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Serial No.

PATENT APPLICATION  
Navy Case No. 78,465

ELECTRICAL POWER ~~DEVICES~~ COOLING TECHNIQUE

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B  
BACKGROUND OF THE INVENTION

Field of the Invention

10 This invention pertains generally to electrical power devices and more particularly to an apparatus for cooling electrical power devices.

Description of the Related Art

15 The power rating of present-day electrical devices, such as power transformers and motors, is limited by heat accumulation due to resistive losses in the copper windings and, in the case of power transformers, to losses from eddy currents and hysteresis within the iron or ferrite cores. It is not generally  
20 recognized that the magnetic flux within a transformer core remains approximately constant when the power output is increased. It is therefore unnecessary to increase the amount of iron or ferrite core material to increase the size of the transformer core in order to deliver more power. The trapped heat produced by the windings while operating at high power is  
25 the major limiting factor for high power transformers.

Different approaches have been attempted to try and remove heat from the core of power transformers. Some of these are the increasing of wire size to reduce resistive losses; immersion of

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the transformer in circulating coolant oil; air cooling of the transformer windings; increasing the operating frequency of the transformer to reduce windings; and increasing the thermal conductivity of the insulating potting compound around the transformer windings. All of these, however, impact on the mechanical size and weight of the transformer designs limiting the use of these applications. Without proper cooling the efficiency and reliability of these transformers and motors are considerably reduced.

#### SUMMARY OF THE INVENTION

The object of this invention is to provide an apparatus for cooling high power electrical devices.

Another object of this invention is to provide a cooler operating high power electrical device that is of light weight, low cost, higher power density, and highly efficient design.

These and other objectives are obtained by placing thermal conductive strips between the turn layers along the axis and perpendicular to the turns of an high power electrical device, such as a transformer or motor, which extends outside of the windings or between the laminates of the core. The excess heat is conducted outward from the interior of the device along the strips to the outside of the device's windings where it is extracted from the protrusions by means of a highly thermal-conductive potting compound that has a short thermal path to a

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small heat sink.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a cutaway view of a transformer with a thermal conductive strip between layers of wire turns around the transformer core.

Figure 2 shows the temperature gradient for a transformer constructed utilizing current state-of-the-art techniques.

Figure 3 shows the temperature gradient for a transformer constructed utilizing a thermal conductive strip technique.

Figure 4 shows a cutaway view of a transformer with a thermal conductive strip between layers of wire turns around the transformer core and a thermocooler.

Figure 5a shows an electric motor with a thermal conductive strip between windings of the motor.

Figure 5b shows a cutaway of a motors laminations with thermal conductive strips interleaved between laminations.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

The apparatus for cooling a high power electrical device, such as a transformer 10, as shown in Figure 1, comprised of various core materials such as laminated iron, ferrite, and other core materials known to those skilled in the art. The

A transformer core 12 is comprised of windings of <sup>electrical</sup> conducting material 14; preferably copper wire, preferably <sup>a flexible, high dielectric electrically</sup> insulated with

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KAPTON<sup>®</sup> type 150FN019, manufactured by DuPont of Wilmington, DE, or similar material, wrapped around the transformer core 12.

A KAPTON<sup>®</sup> type FN-<sup>15</sup>~~3~~ a type HN film coated on one or both sides with TEFLON<sup>®</sup> FEP fluorocarbon resin to impart heat sealability, to provide a moisture barrier and to enhance chemical resistance. The KAPTON<sup>®</sup> prevents electrical shorts between conductors and adjacent layers. Heat is dissipated from the transformer core 12 to ambient through a base plate 17.

10 A thermally conductive material, or strip, 16 placed in preselected locations between the windings of <sup>electrically</sup> conductive material 14, the ends of which protrude outside of the area covered by the conductive material 14. In the example shown in Figure 1 of a completed transformer 10, the thermally conductive material 16 is inserted between every other layer of <sup>electrically</sup> conductive material 14. 15 The thermally conductive strip 16, is preferably a high modulus carbon graphite laminate material, such as an Amoco type K1100X pitch fiber processed by Composite Optics of San Diego, CA. The laminate of the conductive strip 16 is <sup>an anisotropic material that is</sup> highly efficient in conducting heat along the fiber orientation which is 20 unidirectional. An alternative material for the thermally conductive strip 16 is copper or a ceramic, however these have not been found to be as efficient in conducting heat away from the center of a device, such as the transformer 10, as the high modulus carbon graphite laminate material.

25 The thermally conductive strip 16 normally has a smooth

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epoxy surface finish. To improve the thermal interface by as much as 10%, the strips 16 must be lightly scraped with a sharp instrument, such as a razor blade, to remove a small portion of the residual epoxy and fibers left over from the manufacturing process. After scraping, the strip 16 will appear dull with a graphite appearance.

Because the thermally conductive strip 16 normally will have sharp edges on the sides, a narrow glass tape (not shown), approximately 0.005 inches thick, 0.250 inches wide, and having a voltage breakdown of approximately 5 kV, such as 3M glass cloth tape No. 361, a pressure sensitive, 7.5 mil tape good to a temperature of 235°C, manufactured by 3M Electrical Products Division of Austin, TX, is used to buffer the layers of the windings 14 from the thermally conductive ~~material~~ <sup>strip</sup> 16 to prevent damage to the winding 14 coating thereby shorting out the transformer.

The glass tape (not shown) is placed on the edge of the thermally conductive ~~material~~ <sup>strip</sup> 16 on both sides of the strip 16 and offset by one-half the tape width parallel to the strips 16.

In the art this technique is commonly referred to as "butterflying." The application of the glass tape (not shown) forms a wedge adjacent to the edge of the strip 16.

A thermally conductive grease (~~not shown~~), such as type 120-8, manufactured by Wakefield of Wakefield, MA, is placed in the wedge formed by the tape (not shown) and the strip 16; a

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technique well known to those skilled in the art. The strip 16 is installed into the core 12 on top of the thermal grease (not shown) and a second application of the thermal <sup>grease</sup> ~~grease~~ (not shown) is used to cover the strip 16. The thermal grease (not shown) is placed <sup>between</sup> ~~between~~ the two layers of glass tape (not shown) and a second piece of glass tape (not shown) is placed over the first by starting at one edge and lowering the tape (not shown) to the strip 16. A light pressure is used to encompass the two glass tapes (not shown) together and make contact with the strip 16 sealing the thermal grease (not shown) inside of the structure. This is accomplished on both sides of the strip 16, as previously stated. Heat generated within the transformer by resistive losses in the windings of electrically conductive material 14, and due to eddy currents within the core 12 is conducted to the portions of the thermally conductive <sup>strip</sup> ~~material~~ 16 protruding outside of <sup>electrical</sup> ~~the~~ windings of conductive <sup>material</sup> ~~material~~ 14 and in contact with the ferrite core or iron laminates 12.

Surrounding the transformer 10 is a high thermal-conductivity potting compound 22, such as STYCAST® 2850, or similar material. STYCAST® 2850 is a highly filled, castable epoxy system manufactured by Emerson & Cumming, Inc. of Lexington, MA. Potting of the transformer core 12 is accomplished by placing the completed wound copper-core in a mold (not shown) in which potting compound 22 is molded around the transformer core 12 to provide a short thermal path to a base-

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plate main heat sink 17 where excess heat is dissipated to  
surround atmosphere. The mold (not shown) with the transformer  
10 and potting compound 22 is placed into an evacuated chamber  
(not shown) until the potting compound 22 expands to the top of  
5 the mold (not shown) and cured for approximately two hours at  
approximately 100 degrees centigrade. The vacuum atmosphere  
within the chamber (not shown) further forces the thermally  
conductive epoxy (not shown) in and around the windings 14 of the  
completed copper core and the mold profile, thereby, further  
10 enhancing the heat dissipation of the strips 16. The vacuum is  
applied and released a number of times until the potting compound  
22 stops expanding to insure that very little air remains within  
the windings 14 or mold assembly (not shown). This will  
eliminate core failures due to corona. Additional potting  
15 compound 22 may have to be added to the mold (not shown) so as to  
cover completely the windings 14 when done.

The potting compound 22 on a transformer 10 is extended to  
the outer edge of the transformer core 12 on the base plate side  
only. On the other side the potting compound 22 need extend only  
20A past the outer edges of the thermally conductive <sup>strip</sup> material 16.

To prevent mechanical stresses on the transformer core 12  
due to the expansion of the potting compound 22, the mold  
assembly should be designed so as to provide a "head space" or  
gap 23 between the potting compound 22 and the transformer core  
25 12. In assembly this space is filled with a thermal heat sink

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strip , such as SIL-PAD<sup>®</sup> 2000, manufactured by Berquist of Minneapolis, MN.

Alternatively, in place of the potting compound 22, the heat may be conducted from the ends of the thermally conductive strips 16 by the use of a fan (not shown), a technique that is well known to those skilled in the art.

In a design of a test transformer, a 2 kva (2 kW) power transformer providing 1.2 lb/kW was constructed using modern state-of-the-art techniques well known to those skilled in the art. The design measures 3.02 inches by 3.17 inches by 2.22 inches, and weighed 2.4 pounds. In tests, the transformer constructed according to state-of-the-art techniques, after 40 minutes, showed a windings temperature of 200°C at the center of the windings and suffered catastrophic failure due to excess heat (Figure 2).

A duplicate transformer 10 weighing approximately 0.21 lb/kW was constructed utilizing the technology set forth in this invention with the K1100 conductive strips 16 placed within the windings 14 of the transformer. The design measured 3.02 inches by 3.17 inches by 2.22 inches and weighed 2.4 pounds. In tests, the transformer 10 with the thermally conductive strips 16 placed alternately between windings (Figure 1) showed, after approximately 40 minutes, a windings 14 temperature of approximately 70°C without failure (Figure 3).

This invention allows for the reduction in size of a high



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power transformers by a factor of 4 to 8 and a reduction in weight by a factor of 4 to 6, and an increase in power density by 5 to 10 in power. The efficiency of the transformer is improved by maximizing the heat transfer from the transformers interior and minimizing voltage breakdown. The thermal properties of each core 12 will dictate the quantity of thermally conductive ~~material 16~~ <sup>strip 16 material</sup> required to lower the transformer temperature to a predetermined level, some testing may be required to establish the optimal amount needed to provide proper cooling.

When additional cooling is required or to raise the power of a transformer 20, as shown in Figure 4, a thermocooler 18, such as a ~~model~~ <sup>Model</sup> CP2-127-06-7 made by Melcon of Trenton, NJ, may be applied to the outside of the transformer 20. The thermocooler 18, with or without a cooling fan (not shown). Control of the thermocooler 18 may be such that it could be turned on and off as cooling demands raise and lower. The thermocooler 18 may ~~either~~ be attached to the outer portions of the transformer 20 where it could be easily removed for replacement, if required. In some instances it may be desirable to selective control the operation of the thermocooler 18, therefore a control device such as a timer (not shown) or thermal switch (not shown) may be integrated into the transformer 20 package to either increase the thermal conductivity or decrease it by switching the thermocooler on or off, as desired.

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Although this embodiment has been described in relation to an exemplary device such as a transformer, the claimed invention may equally well be utilized in other types of electrical devices where internal heat is a problem, such as motors, modulation transformers, etc. The size of the transformer is not of concern, it may vary from a small transformer used in switching power supplies to power transformers used in electrical distribution systems. Further, the frequency of the electrical current within the devices to be cooled is irrelevant, e.g., 60 cycles to 400 cycles operate the same thermally. High frequency transformers have higher copper losses due to skin effects. This additional heat may also be removed by the thermally conductive ~~material~~<sup>strip</sup>, as set forth in this invention.

When applied to electrical motors 30, as shown in Figure 5a, pieces of thermally conductive ~~material~~<sup>strip</sup> 16 are placed between windings of the motor 30 or interleaved into vertically stacked motor laminations 32, as shown in Figure 5b. The internal heat from the motor laminations 32 and windings 36 is conducted from the interior of the motor 30 to the outer portions where the heat is then dissipated through the motor case 34 to ambient atmosphere.

Although the invention has been described in relation to the exemplary embodiment thereof, it will be understood by those skilled in the art that still other variations and modifications can be affected in the preferred embodiment without detracting

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from the scope and spirit of the invention as stated in the  
claims.

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